Microwave Sensing From Geostationary Orbit

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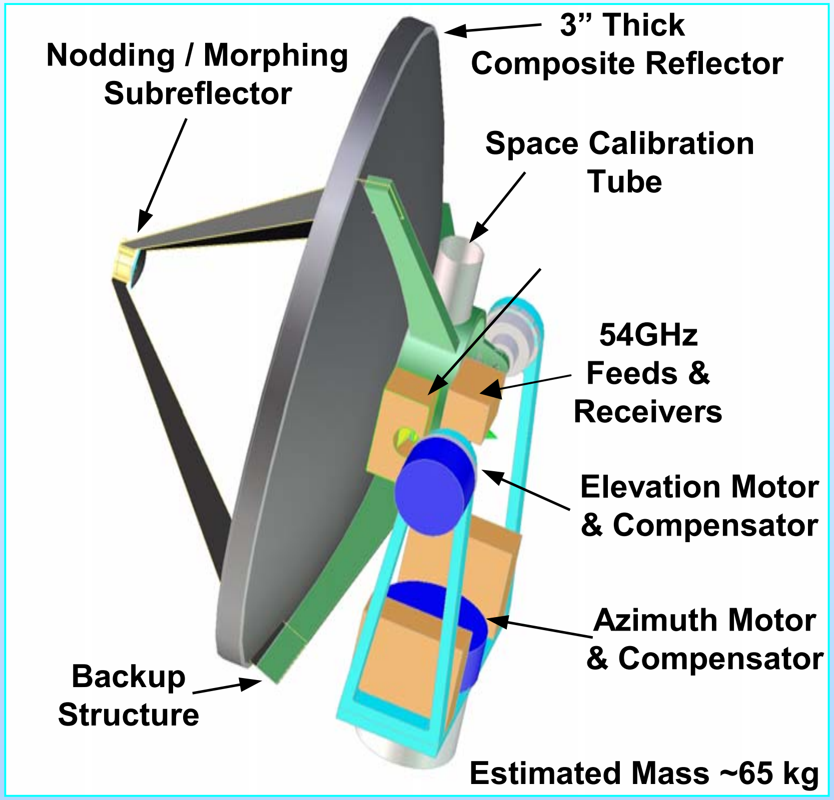
GMSWG* Concept Summary

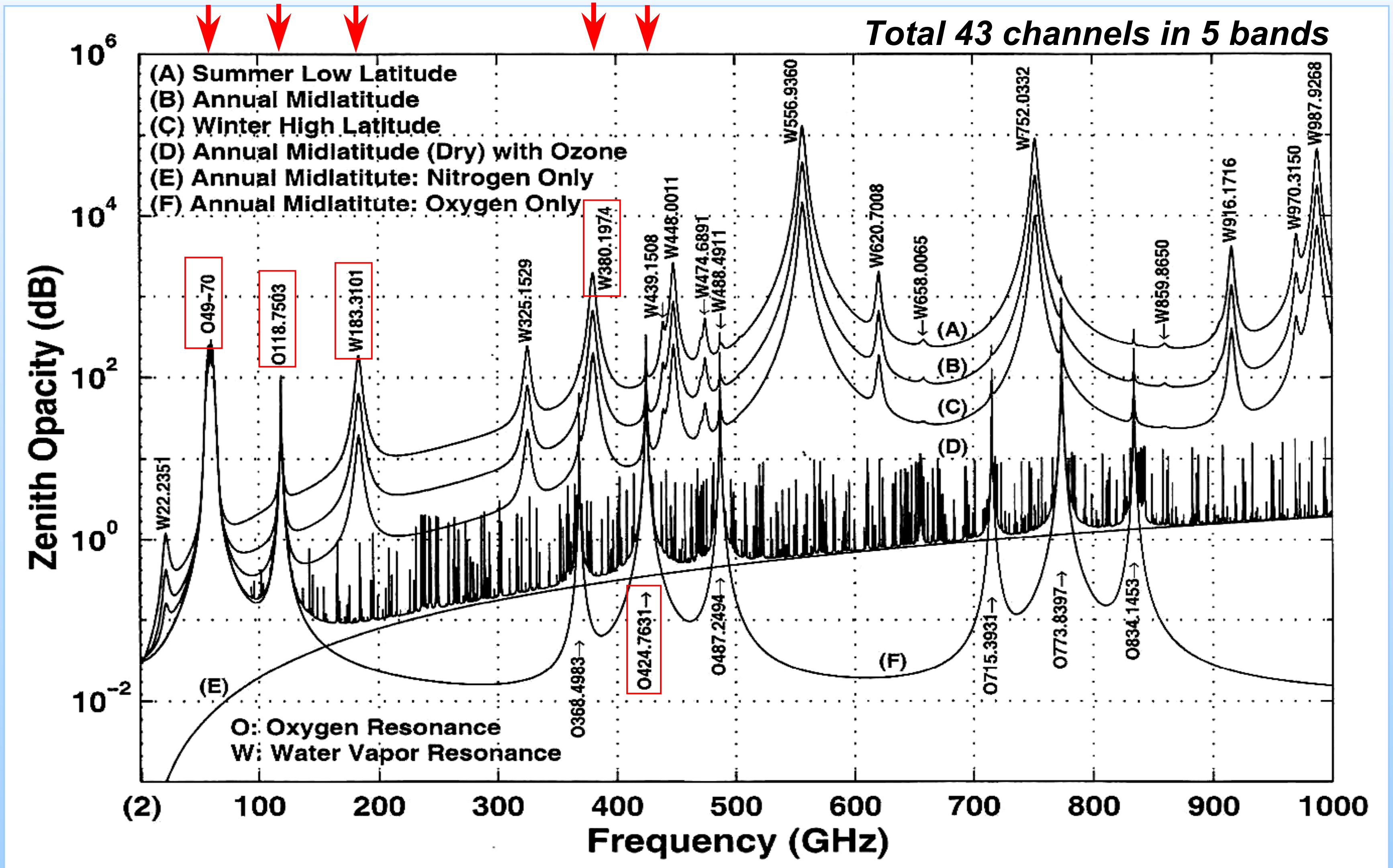
GEosynchronous Microwave (GEM) Sensor

- Baseline system using 54, 118, 183, 380, and 424 GHz with ~2-meter diameter aperture.
- ~16 km subsatellite resolution (~12 km using oversampling) above 2-5 km altitude at highest frequency channels.
- The 380 and 424 GHz channels selected to map precipitation through most optically opaque clouds at sub-hourly intervals.
- Temperature and humidity sounding channels penetrate clouds sufficiently to drive NWP models with hourly data.
- Estimated 2002 costs: $31M non-recurring plus ~$28M/unit.

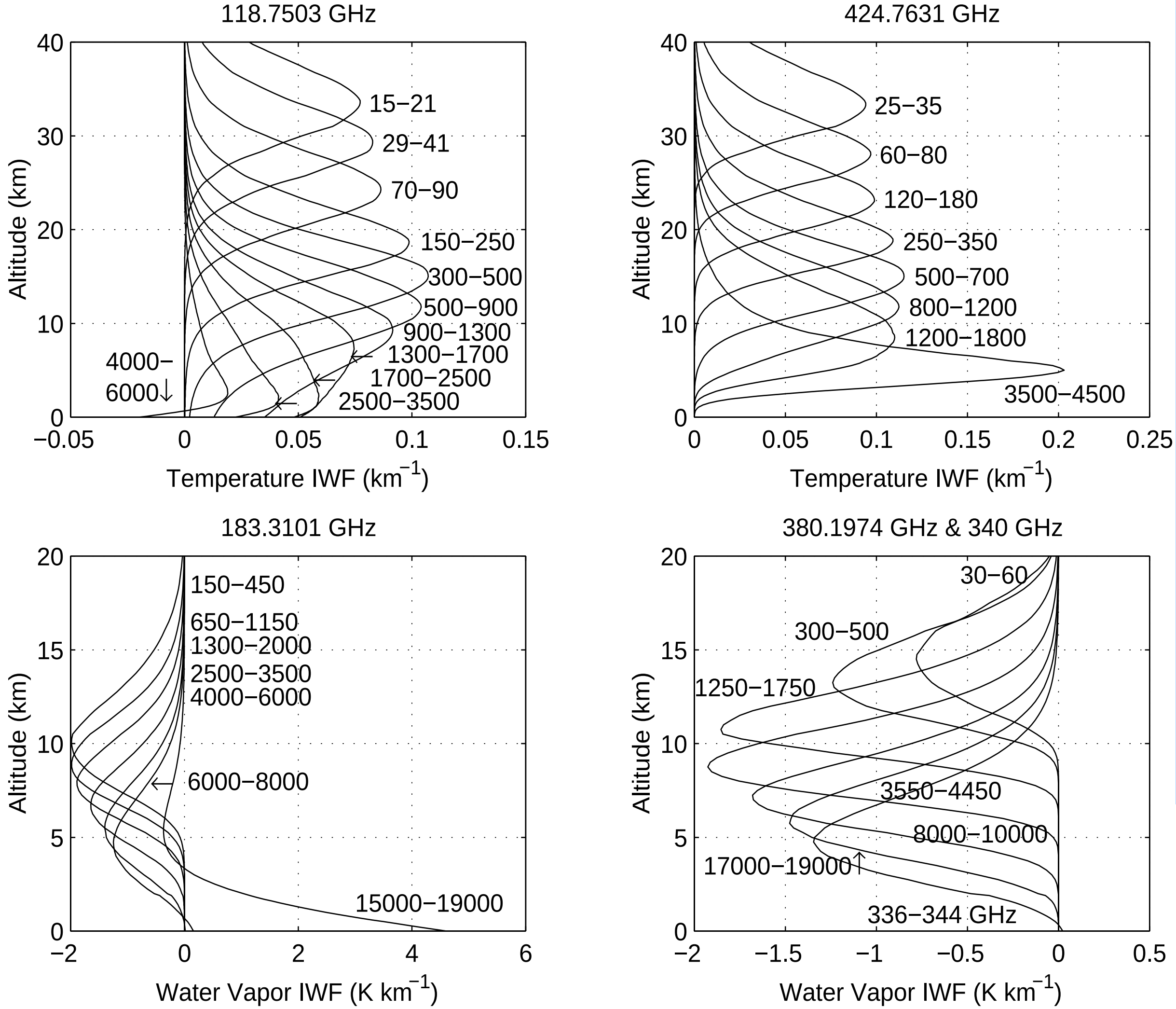


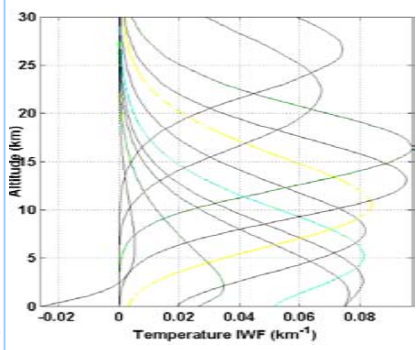
* Geosynchronous Microwave Sounder Working Group, Chair: D.H. Staelin (MIT)

GEM Spectral Selection



GEM Vertical Response

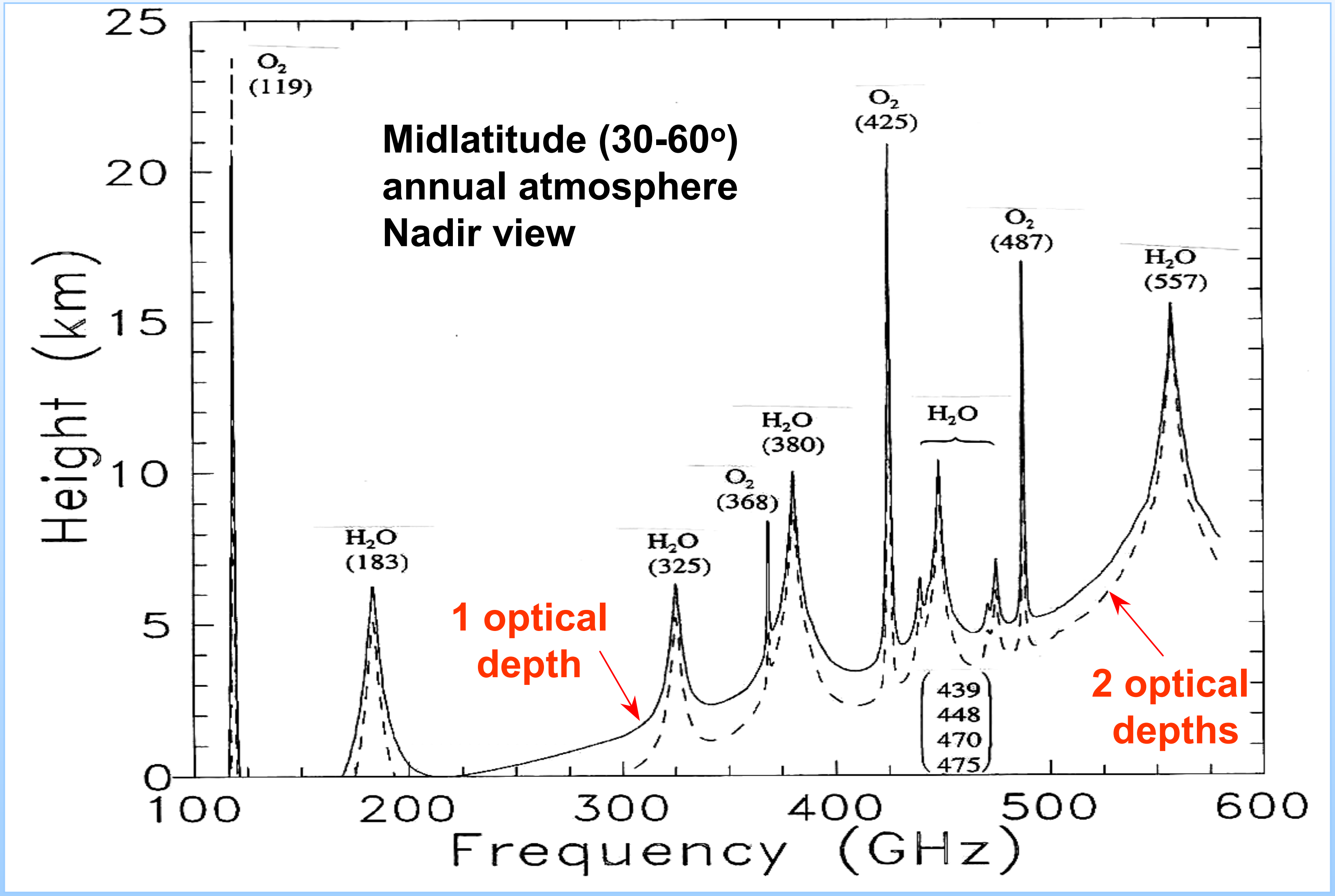




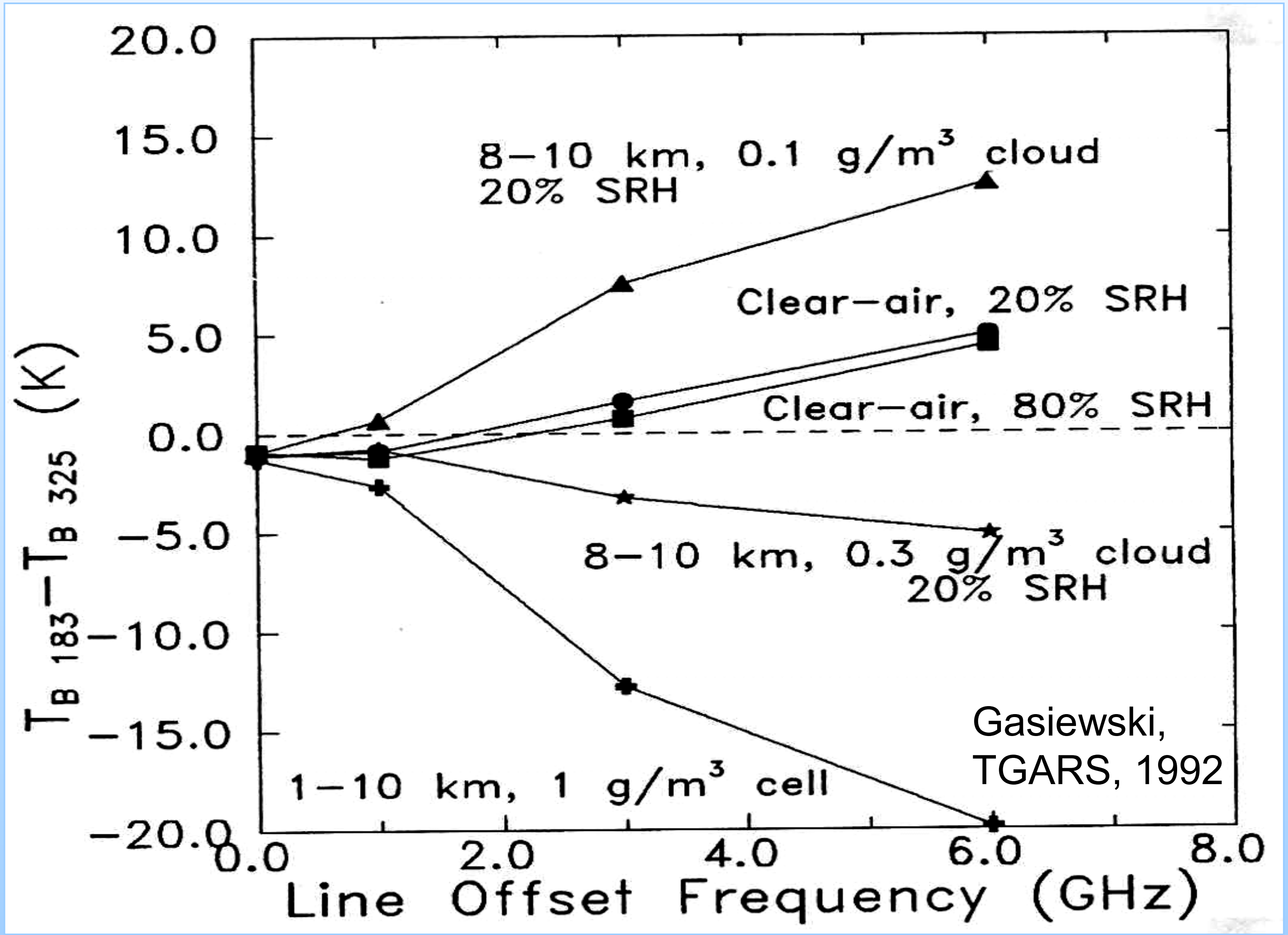
AMSU
5-MM

Klein & Gasiewski,
JGR-ATM,
July 2000.

GEM Probing Depths



Similar Channel (183 / 325 GHz) Response to Clouds



GEM Spatial Resolution

Frequency (GHz)		Aperture size (m) 0.1	0.25	0.5	1	1.5	2	4.4	8	15	30	Tolerance (mm)
6.8	W	19611.0	7844.4	3922.2	1961.1	1307.4	980.5	445.7	245.1	130.7	65.4	1.764
10.7	W	12463.1	4985.2	2492.6	1246.3	830.9	623.2	283.3	155.8	83.1	41.5	1.121
18.7	W	7131.3	2852.5	1426.3	713.1	475.4	356.6	162.1	89.1	47.5	23.8	0.641
37.0	W	3604.2	1441.7	720.8	360.4	240.3	180.2	81.9	45.1	24.0	12.0	0.324
56.0	O2	2381.3	952.5	476.3	238.1	158.8	119.1	54.1	29.8	15.9	7.9	0.214
89.0	W	1498.4	599.3	299.7	149.8	99.9	74.9	34.1	18.7	10.0	5.0	0.135
118.8	O2	1123.0	449.2	224.6	112.3	74.9	56.1	25.5	14.0	7.5	3.7	0.101
166.0	W	803.3	321.3	160.7	80.3	53.6	40.2	18.3	10.0	5.4	2.7	0.072
183.3	H2O	727.5	291.0	145.5	72.8	48.5	36.4	16.5	9.1	4.9	2.4	0.065
220.0	W	606.2	242.5	121.2	60.6	40.4	30.3	13.8	7.6	4.0	2.0	0.055
325.1	H2O	410.2	164.1	82.0	41.0	27.3	20.5	9.3	5.1	2.7	1.4	0.037
340.0	W	392.2	156.9	78.4	39.2	26.1	19.6	8.9	4.9	2.6	1.3	0.035
380.2	H2O	350.7	140.3	70.1	35.1	23.4	17.5	8.0	4.4	2.3	1.2	0.032
424.8	O2	313.9	125.6	62.8	31.4	20.9	15.7	7.1	3.9	2.1	1.0	0.028
448.0	H2O	297.7	119.1	59.5	29.8	19.8	14.9	6.8	3.7	2.0	1.0	0.027
556.9	H2O	239.5	95.8	47.9	23.9	16.0	12.0	5.4	3.0	1.6	0.8	0.022
620.0	H2O	215.1	86.0	43.0	21.5	14.3	10.8	4.9	2.7	1.4	0.7	0.019
752.0	H2O	177.3	70.9	35.5	17.7	11.8	8.9	4.0	2.2	1.2	0.6	0.016
916.2	H2O	145.6	58.2	29.1	14.6	9.7	7.3	3.3	1.8	1.0	0.5	0.013
987.9	H2O	135.0	54.0	27.0	13.5	9.0	6.7	3.1	1.7	0.9	0.4	0.012

- 3-dB best resolution degrades by ~1.3x to ~21 km at 50^{o} latitude.
- Oversampling by ~2x above Nyquist expected to recover ~30-40% of this lost resolution for high SNR cases.

GEM Sensitivity & Scan Mode

- **Regional** (1500 x 1500 km^2) : 12-15 minutes

Band (GHz)	3-dB IFOV (km, SSP)	Deconvolved Resolution (km, SSP)	ΔT_{RMS} (K)	ΔT_{RMS} Required (K,SNR=100)
50-56	138.6	~104	0.04-0.1 ✓	0.1-0.6
118.705	60.2	~45	0.07-0.9 ~	0.1-0.6
183.310	41.9	~31	0.06-0.2✓	0.3-0.6
380.153	20.5	~16	0.03-3.4 *	0.3-0.5
424.763	16.4	~12	1.0-9.5 *	0.4-0.6

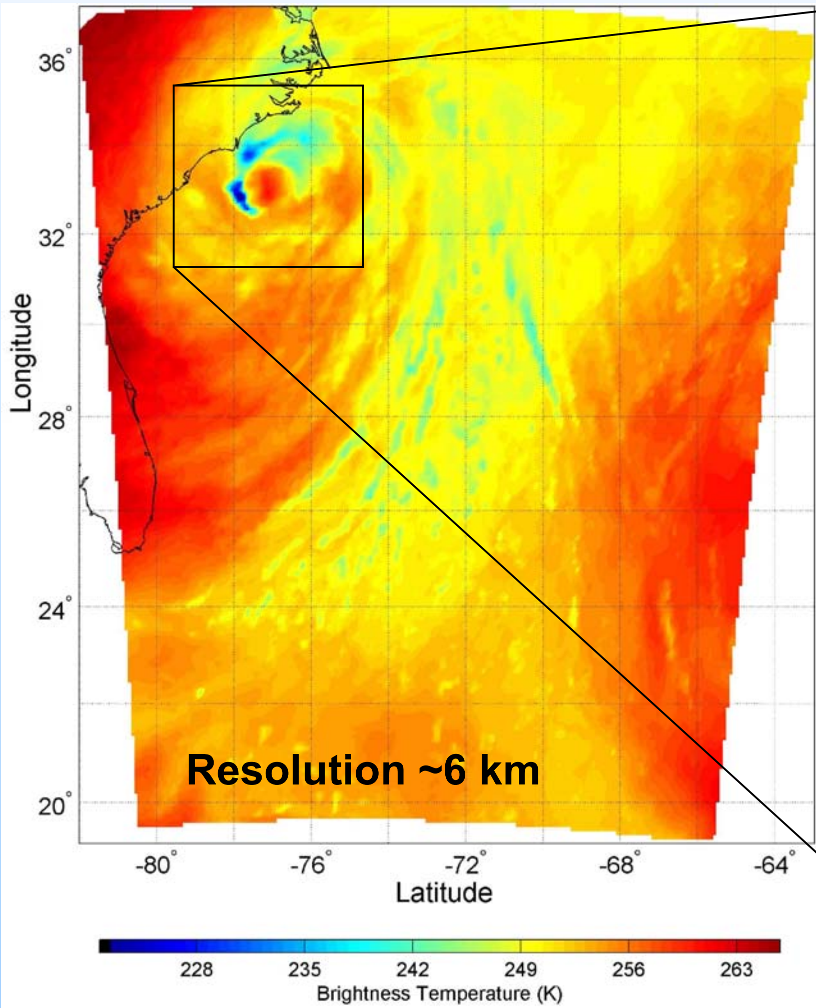
Assumptions:

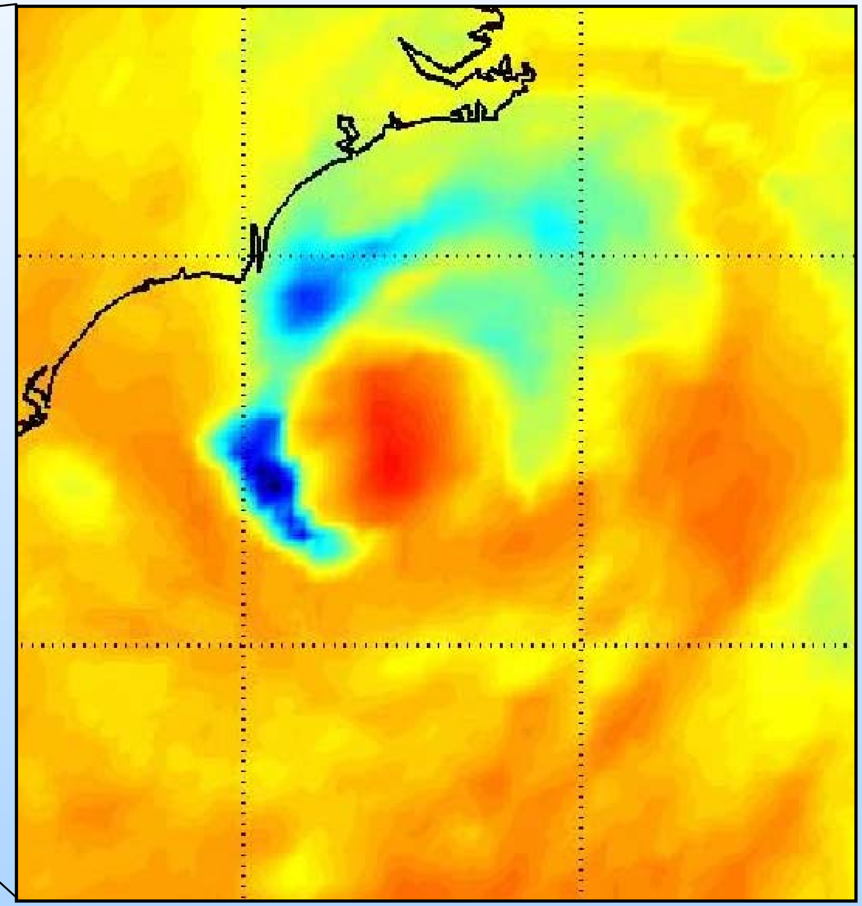
- Averaging (downsampling) of beams to fundamental deconvolved resolution.
- * Further reductions in ΔT_{RMS} achievable via additional downsampling and/or time averaging.

- **CONUS** imaging time (3000 x 5000 km^2) : 90 minutes

GEM Simulated Imagery

Hurricane Bonnie August 26, 1998 1500 UTC





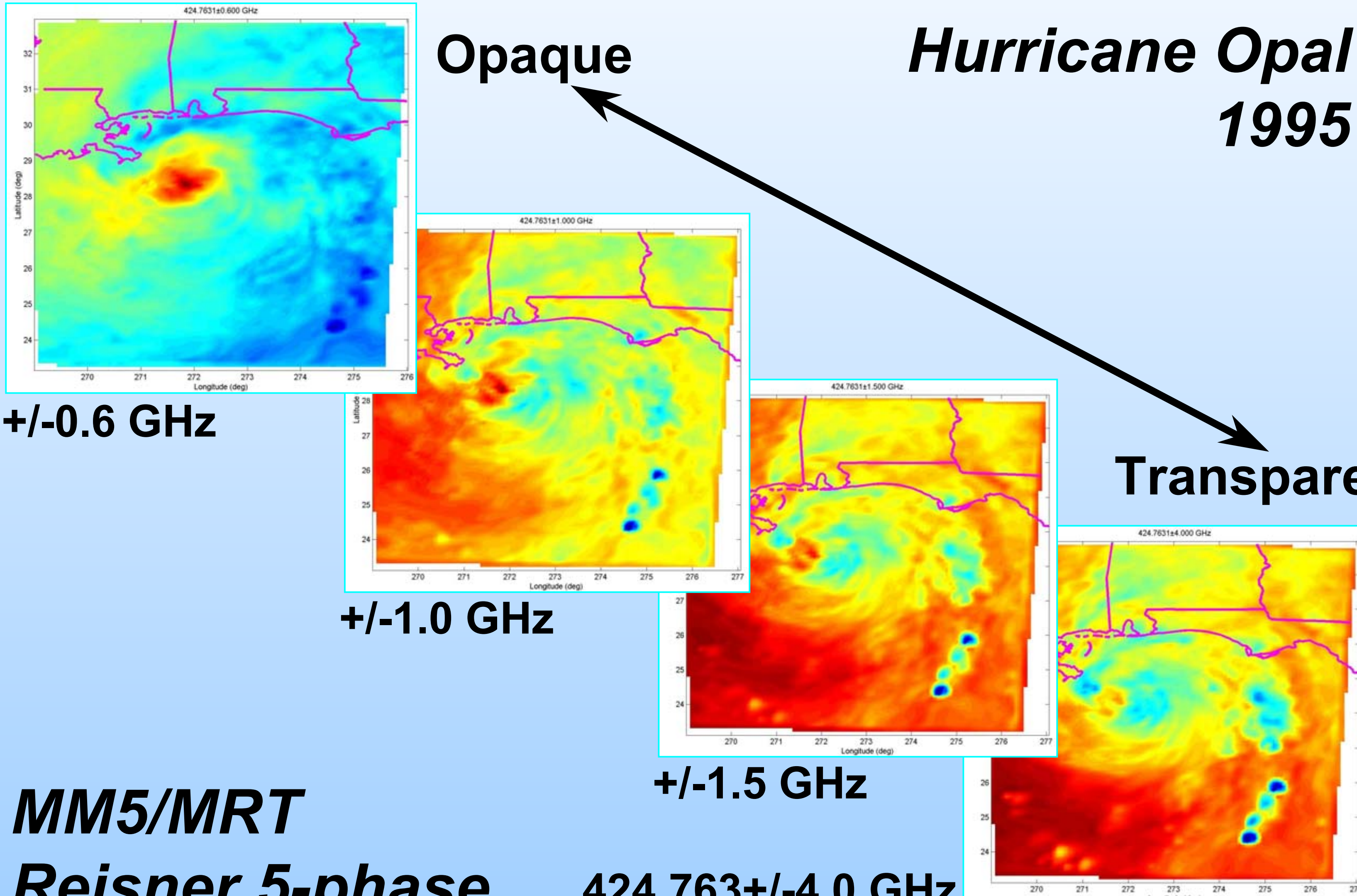
Regional Scan Mode (1500 x 1500 km^2)

MM5/MRT Reisner 5-phase with DO RT model at 424.763+/-4.0 GHz

GEM Simulated Imagery

Spectral Response

Hurricane Opal 1995



+/-0.6 GHz

+/-1.0 GHz

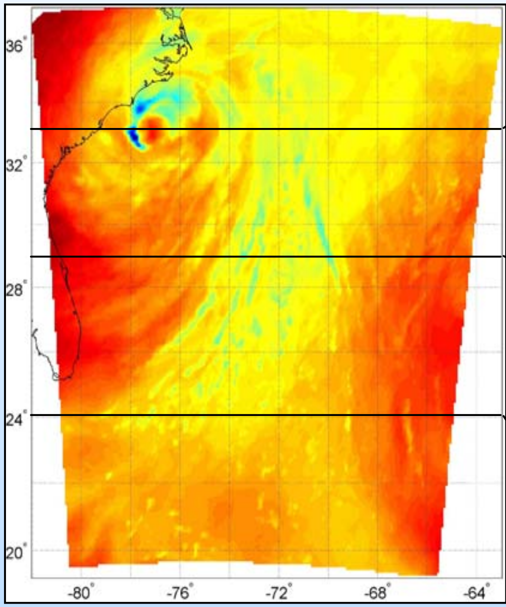
+/-1.5 GHz

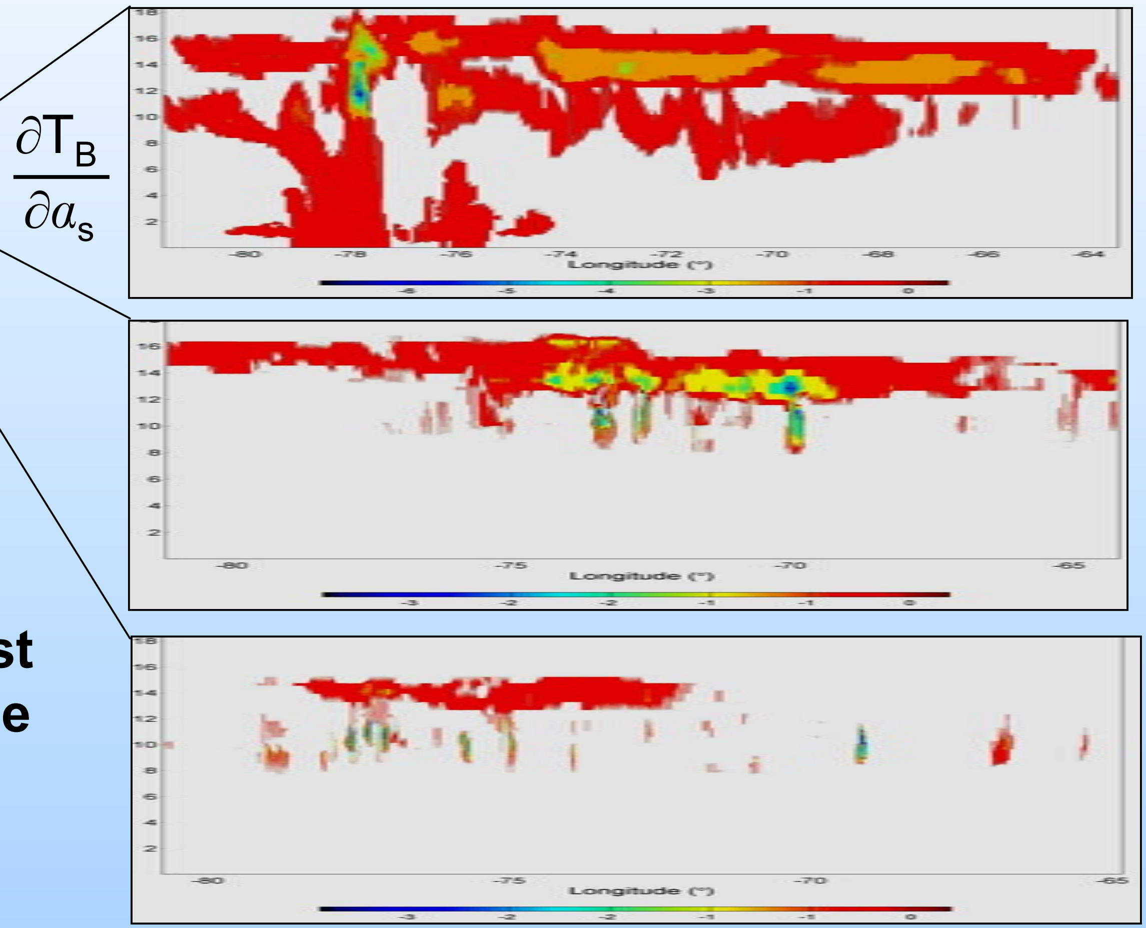
424.763+/-4.0 GHz

MM5/MRT

Reisner 5-phase

GEM Jacobian for Radiance Assimilation

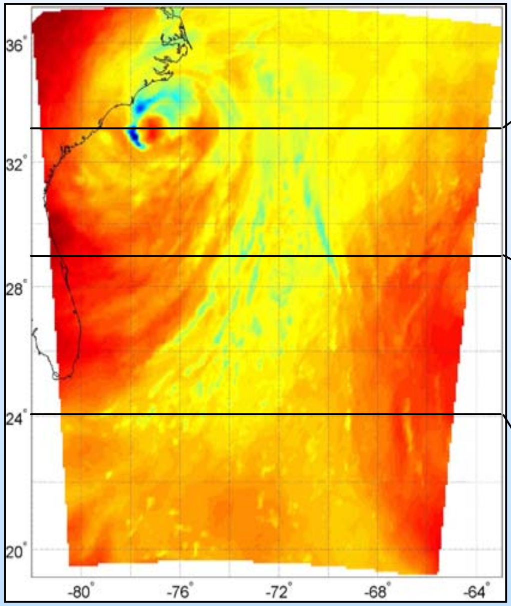




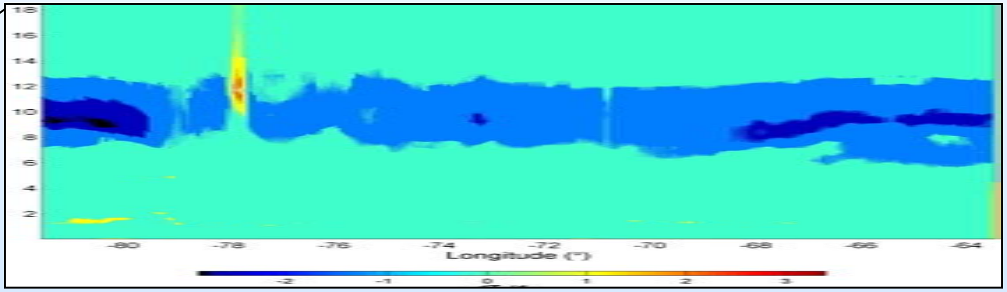
Discrete-Ordinate fast Jacobian for real-time calculation of $\frac{\partial T_B}{\partial p_i}$.

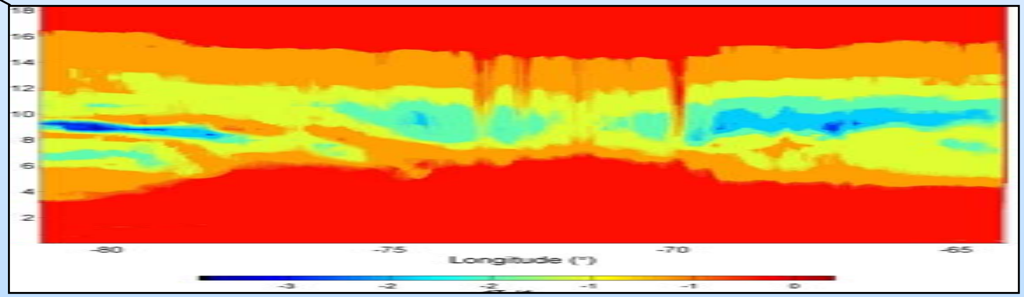
Hurricane Bonnie, August 26, 1998, 1500 UTC
MM5/MRT Reisner 5-phase with DO RT model at 424.763+/-4.0 GHz

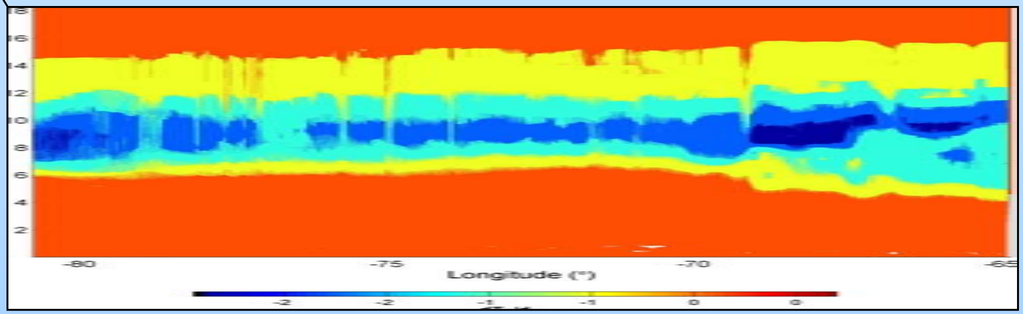
GEM Jacobian for Radiance Assimilation



$$\frac{\partial T_B}{\partial \alpha_a}$$







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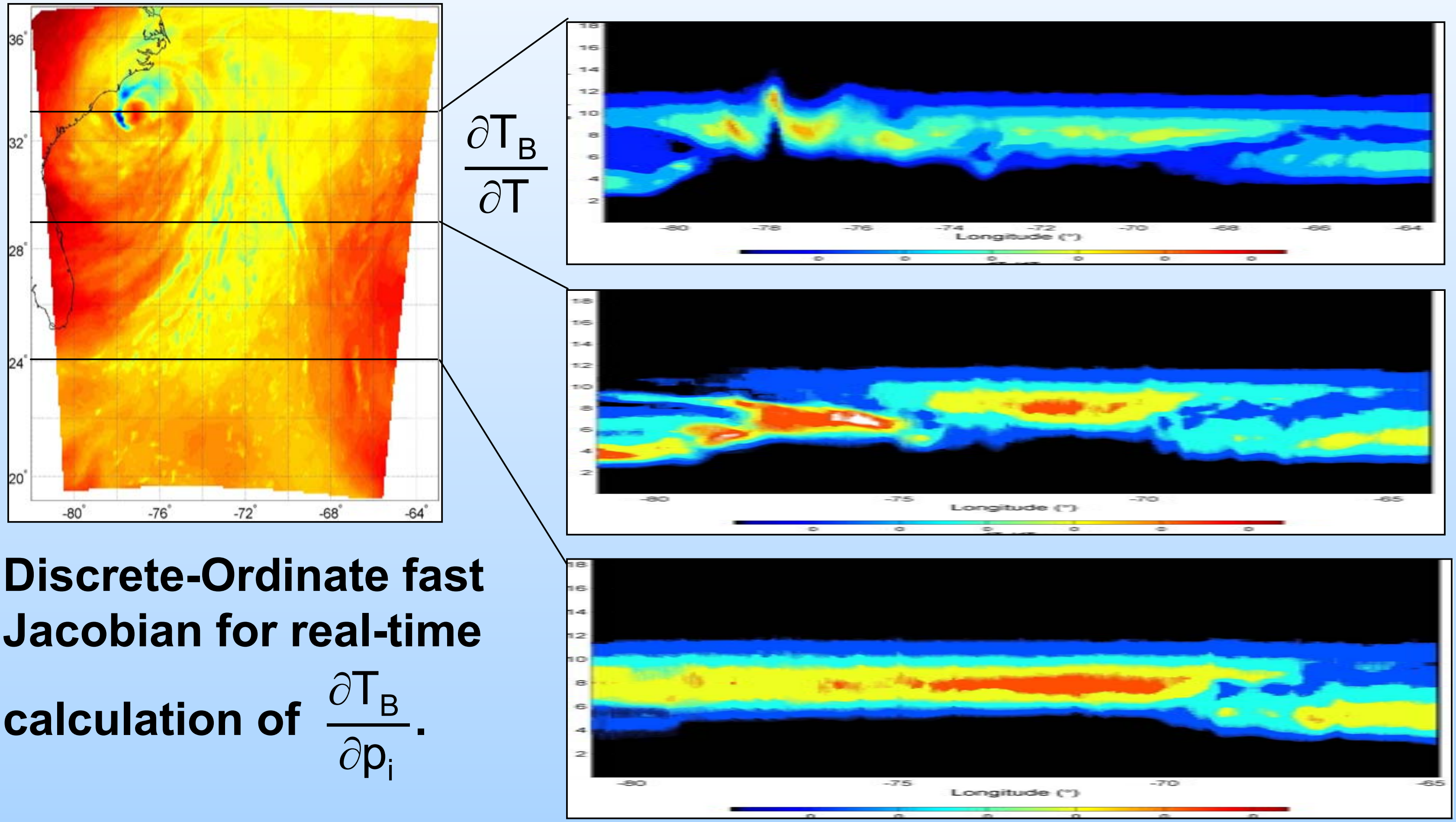

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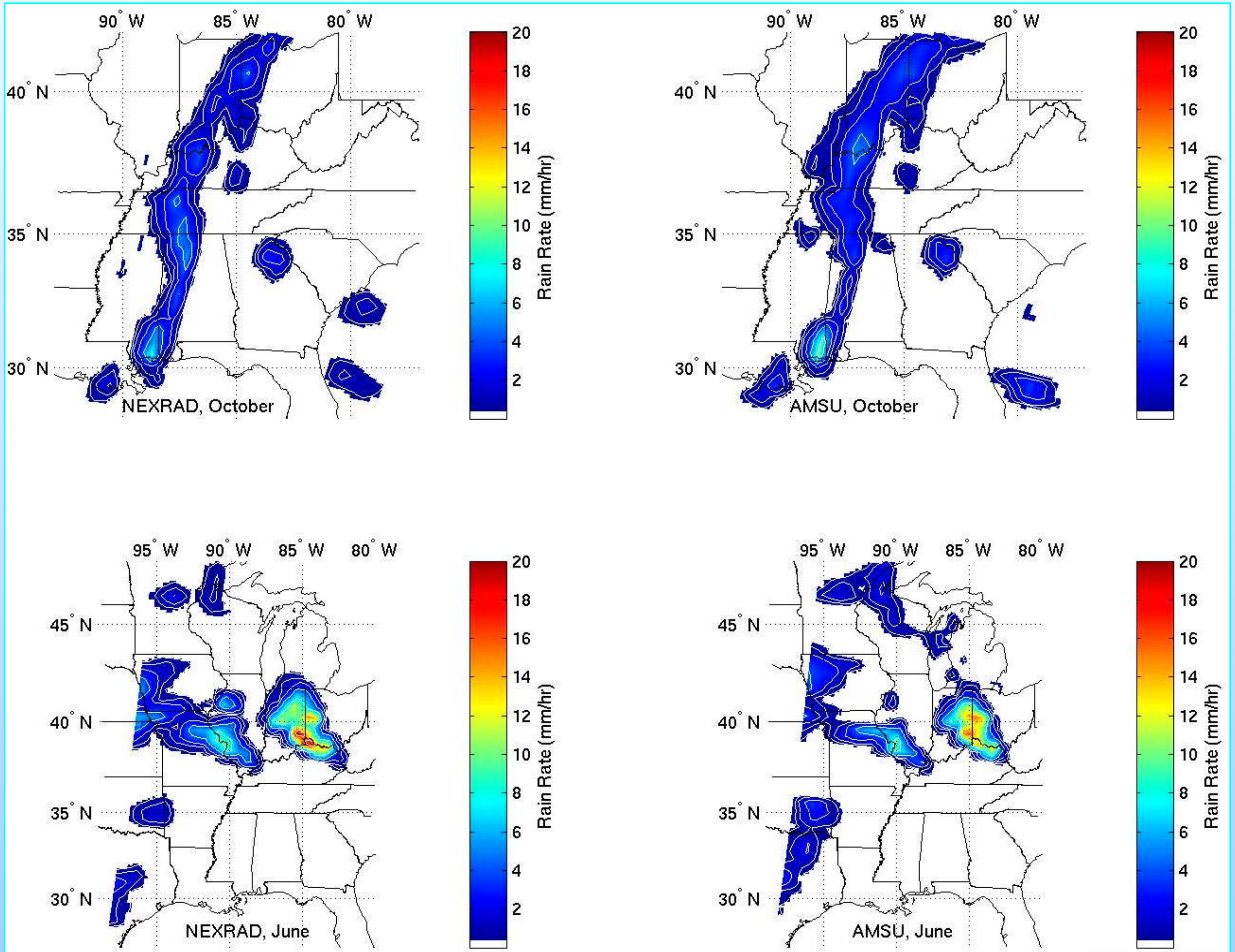
Hurricane Bonnie, August 26, 1998, 1500 UTC
MM5/MRT Reisner 5-phase with DO RT model at 424.763+/-4.0 GHz

AMSU Precipitation Retrievals

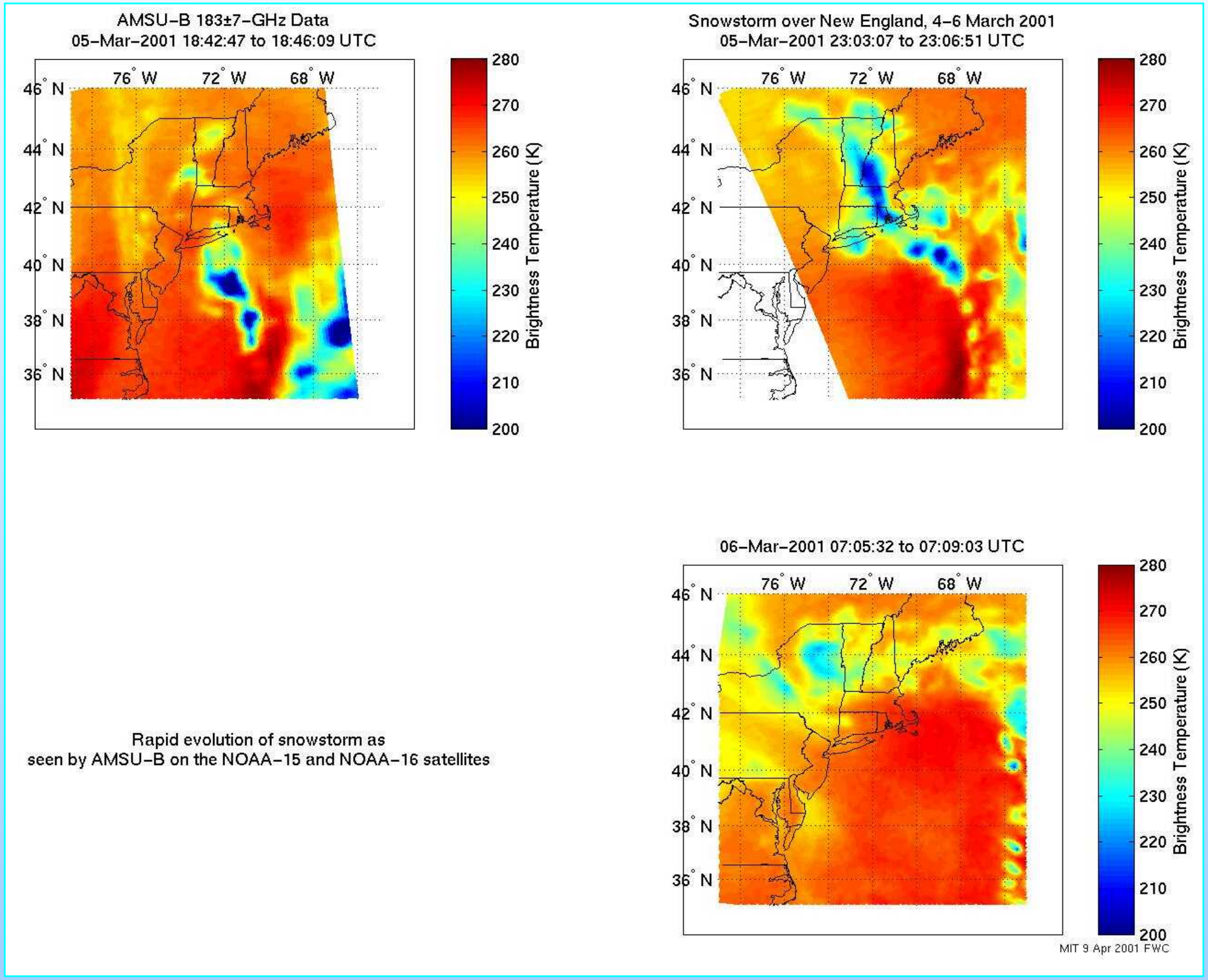


Comparison of 50–km NEXRAD and AMSU precipitation–rate retrievals
for 11 June 1998, 13:37 UTC, and 7 Oct 1998, 13:43 UTC

NOAA-15 AMSU with neural net retrieval, 50 km resolution

Staelin & Chen, *IEEE TGARS,* September 2000.

Rapid Precipitation Evolution

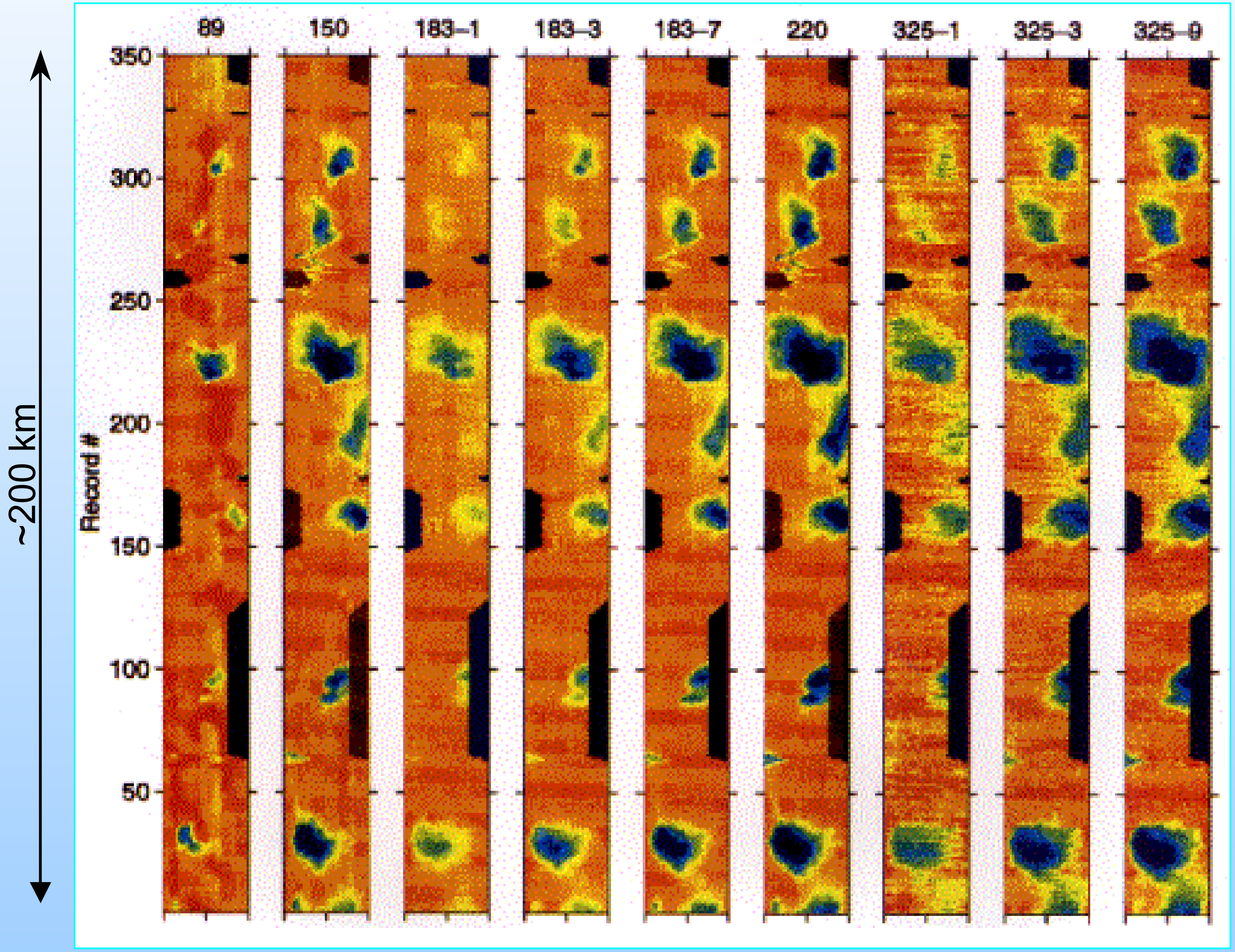


March 5-6 2001 snowstorm observed using AMSU-B

4 and 8 hr time gaps

Major evolution can occur on short time scales!

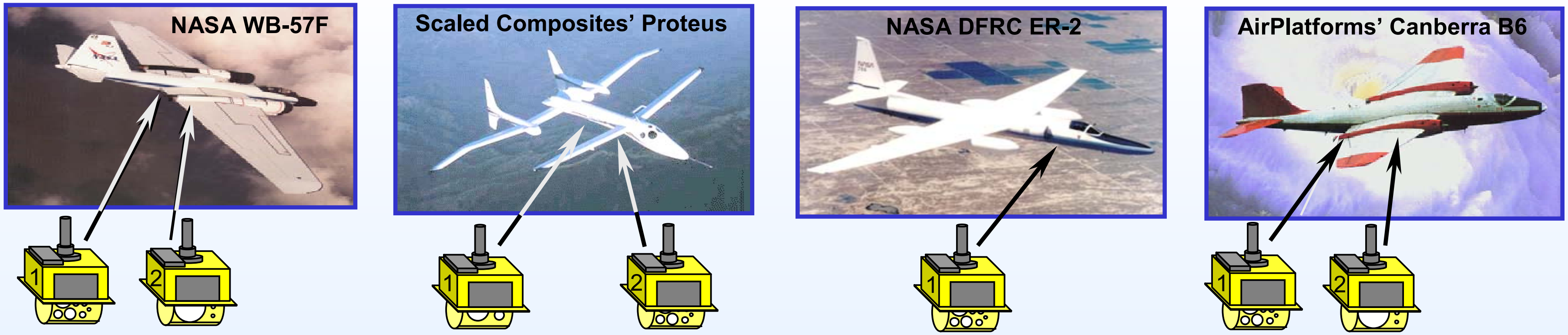
Airborne SMMW Imagery



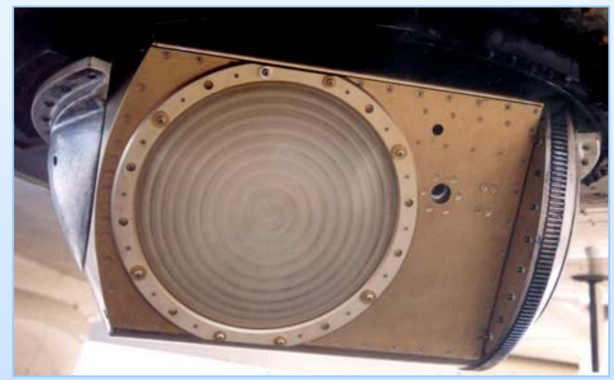
Maritime convection observed at 20 km altitude.

Many cells missed at 89 GHz!

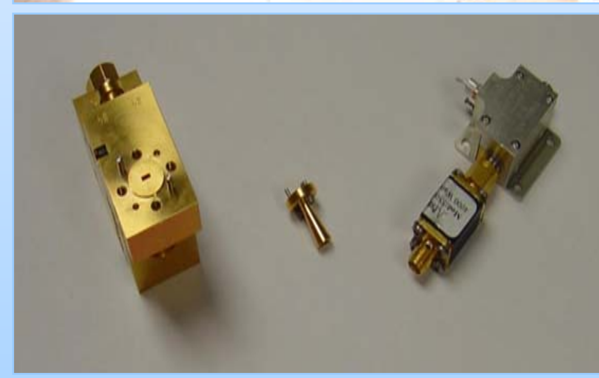
Gasiewski, et al, Proc. 1994 IGARSS, Pasadena, USA.



PSR/CX:	5.82-6.15	(v,h)	10°	
1999 (C)	6.32-6.65	(v,h)	10°	
	6.75-7.10	(v,h,U,V)	10°	
	7.15-7.50	(v,h)	10°	
2002 (CX)	10.6-10.8	(v,h,U,V)	7°	
	10.68-10.70	(v,h)	7°	
	9.6-11.5 um IR	(v+h)	7°	



PSR/S:	18.6-18.8	(v,h,U,V)	8°	
~2002-	21.4-21.7	(v,h)	7°	H_2O
2003	36-38	(v,h,U,V)	7°	
	52.6-57.5x7	(v)	3.5°	O_2
	86-92	(v,h,U)	3.5°	
	118.750 x 7	(v)	3.5°	O_2
	183.310 x 7	(v)	1.8°	H_2O
	325.153 x 3	(v)	1.8°	H_2O
	337-343	(v,h,U)	1.8°	
	380.197 x 5	(v)	1.8°	H_2O
	424.763 x 5	(v)	3.5°	O_2
	496-504	(v,h)	1.8°	
	9.6-11.5 um IR	(v+h)	1.8°	



GEM Airborne Simulator

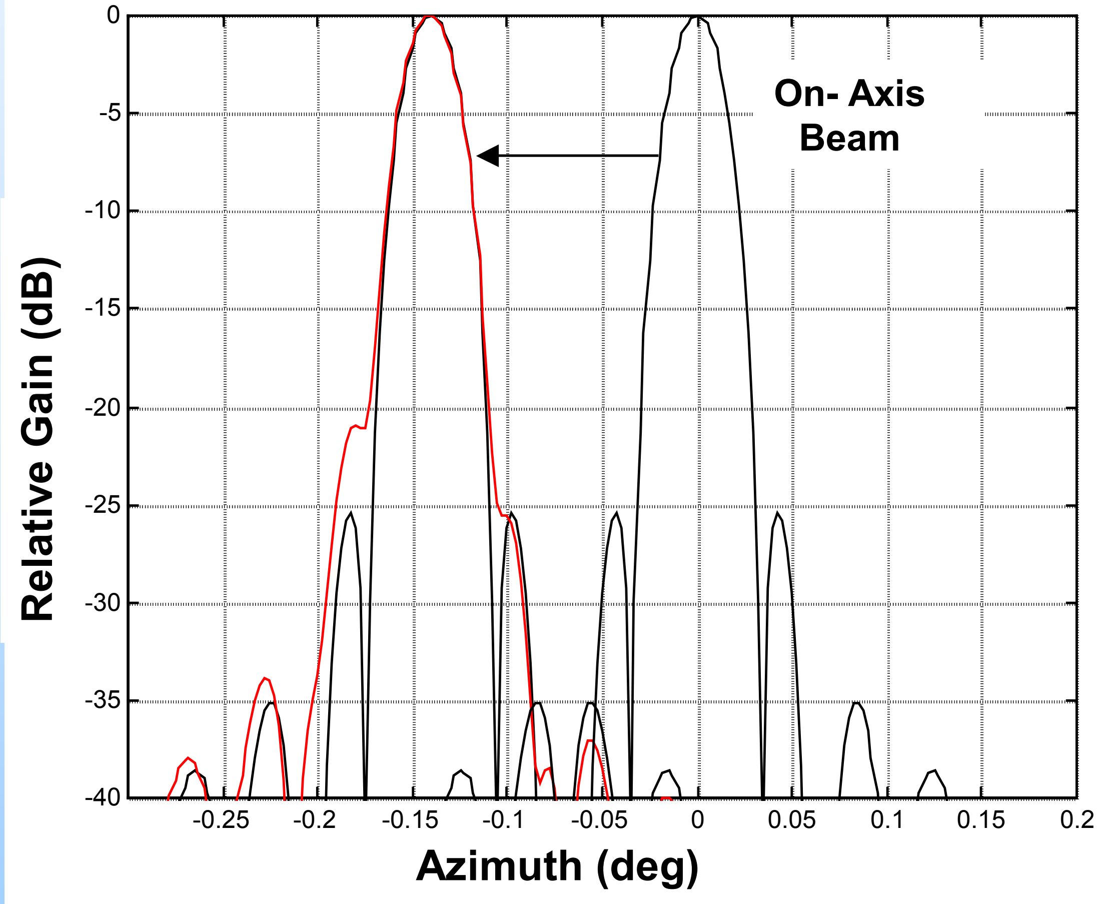
PSRCX and PSR/S Scanhead Suite

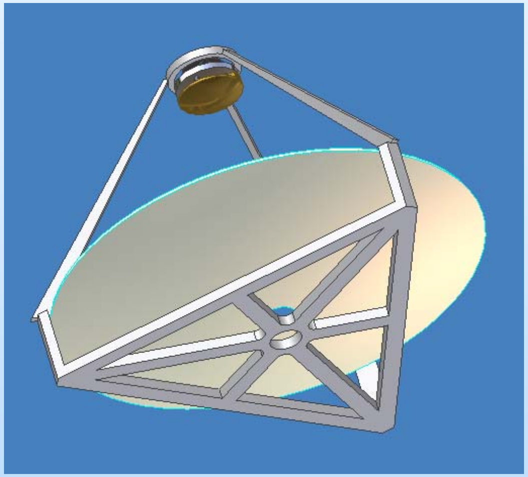
& Aircraft Compatibility

GEM Antenna Studies

Main Beam Microscanning

5 beam scan (0.14°) at 424 GHz from tilting/decentering subreflector and 2-m reflector (MIT/Lincoln Labs)





Concept design of GEM antenna with tilting/decentering subreflector (Ball ATC)

GEM Cost/Benefit for GPM

#Additional Drones	Repeat Time	Cost ($M)	
1	2.4 (hrs)	40	
2	2.0	80	Single HS cost break-point
3	1.7	120	
4	1.5	160	
5	1.3	200	
6	1.2	240	Global cost break-point
7	1.1	280	
8	1.0	320	
9	55 (mins)	360	
10	51	400	
15	38	600	
20	30	800	
25	25	1000	
30	21	1200	
35	18	1400	
40	16	1600	

Assumptions:
GEM recurring cost of $30M + $60M bus & launch = $90M
TMI-class passive drone cost of $10M + $30M bus+launch = $40M
3 NPOESS + GPM PR as GPM baseline system – costed as fixed
3 GEMs required for global tropical/midlatitude coverage

Recent U.S. GEM Proposals

- **Geostationary Microwave (GEM) Observatory** – Concept proposal to NASA/HQ in response to Instrument Incubator Program AO – Based on 2-meter antenna and channels at 54/118/183/380/424 GHz (Staelin et al, 1998).

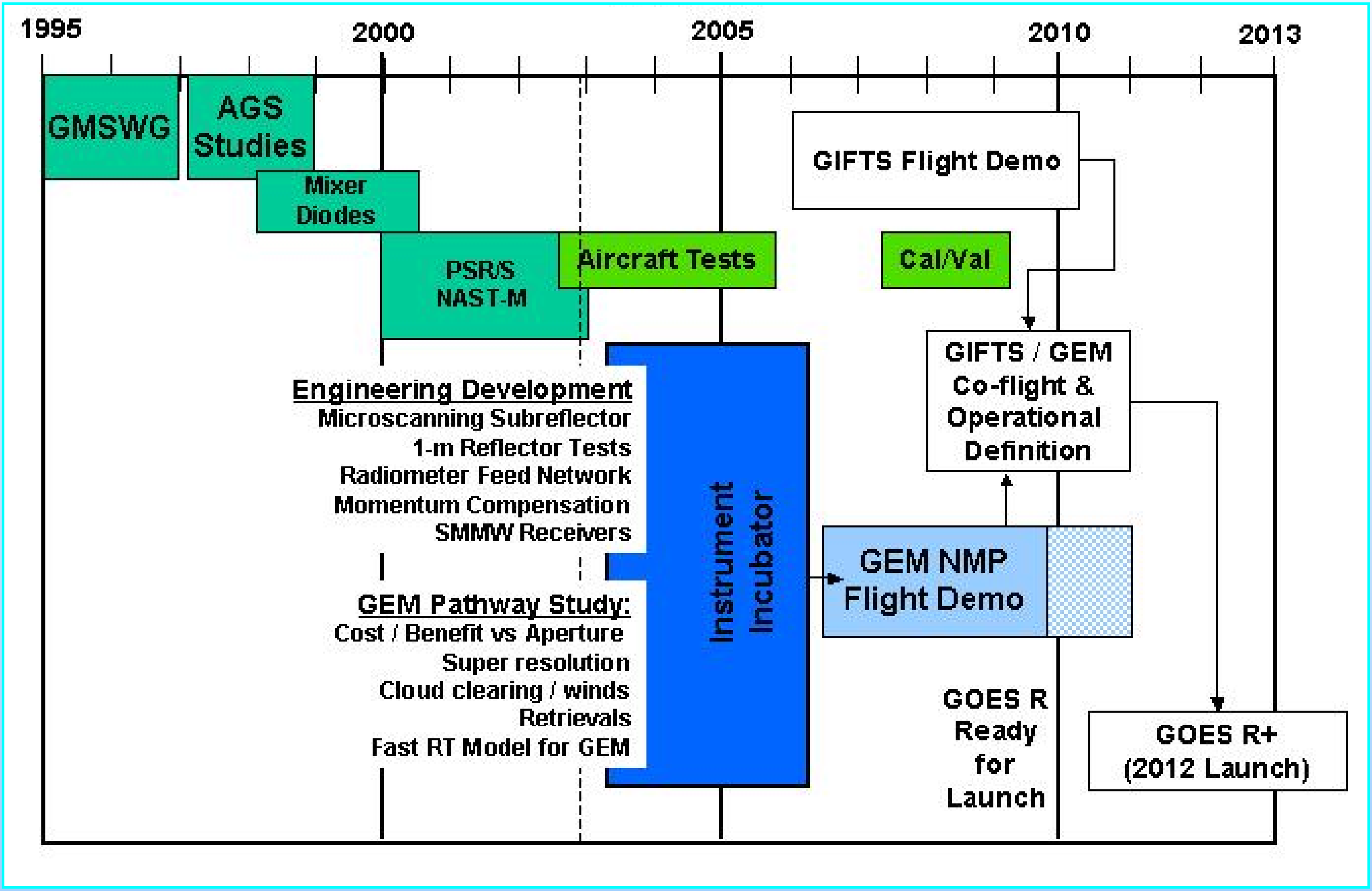
- **EO-3 Geosynchronous Microwave (GEM) Observatory** New Millennium proposal submitted by NOAA/ETL, NASA/GSFC, MIT/LL to NASA/HQ. Based on a GEM demonstration unit with spatial resolution of 13-20 km, 2-meter antenna (Gasiewski et al, 1998).

- **GEosynchronous Microwave (GEM) Precipitation Sounder** – Phase B proposal submitted by NASA/LaRC, NOAA/ETL, MIT/LL to NASA/HQ Instrument Incubator Program. Focused on antenna technology development and demonstration (Lawrence et al, 2001).

Recent U.S. GEM Proposals (cont'd)

- **Geosynchronous Microwave (GEM) Observatory for Hydrological Imaging and Profiling** – Technology development proposal to NASA/HQ in response to Instrument Incubator Program AO – Based on 2-meter antenna and channels at 54/118/183/380/424 GHz (Gasiewski et al, 2002). Includes industry-based development of prototype microscanning subreflector.

GEM Roadmap to Operations



GOMAS Proposal to ESA

- Proposal to ESA Earth Explorer Opportunity Missions: “Geostationary Observatory for Microwave Atmospheric Sounding” – submitted Jan 2002.

- PI: B. Bizzarri, many European and U.S. partners.

- Based on U.S. GEM baseline design, but free flyer with larger antenna (3-m) to compensate for application at higher European latitudes (antenna cost ~$d^{2.5}$).

- 3-year science demo phase, 5-yr design lifetime, 10 km best resolution w/o deconvolution, 15 minute best update. Launch ~2008+, cost 160 M€ total, including ground segment

- To be considered for further scientific and technological study within ESA

GEM Summary

- GEM will be a cost-effective AMSU-like sounder/imager but with time-resolved observations of precipitation – complementary to HES, GIFTS.
- Convective PR anticipated to be measurable over both land and water along with sounding products within clouds, ~15 km midlatitude spatial resolution.
- GEM concept study completed, antenna and scanning technology under development (MIT/LL, NOAA/ETL)
- Aircraft demonstrations under development (NOAA, MIT)
- RT model and retrieval simulations in progress (NOAA)
- European GOMAS concept proposal submitted to ESA (Jan 2002), GOMAS science studies planned (2003).
- Demonstration of operational system possible within GPM and NPOESS timeframe. GOES R+ ~2012+ (?)